NH3 Fuel - Gaining Momentum

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NH3 X

September 22 – September 25, 2013

Sacramento, California

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Outline

- Why NH3? – environmental, energy security, economics, safety
- Environmental – second to none, very efficient
- Energy Security – flexible, practical, affordable
- Cost – between coal/nat. gas and gasoline
- Safety – as safe as it needs to be – can meet any required level.

NH3 Fuel Advantages

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Production Flexibility – Wind, Solar, Biomass, Nuclear, Coal , Natural Gas, etc.

Existing Delivery Infrastructure

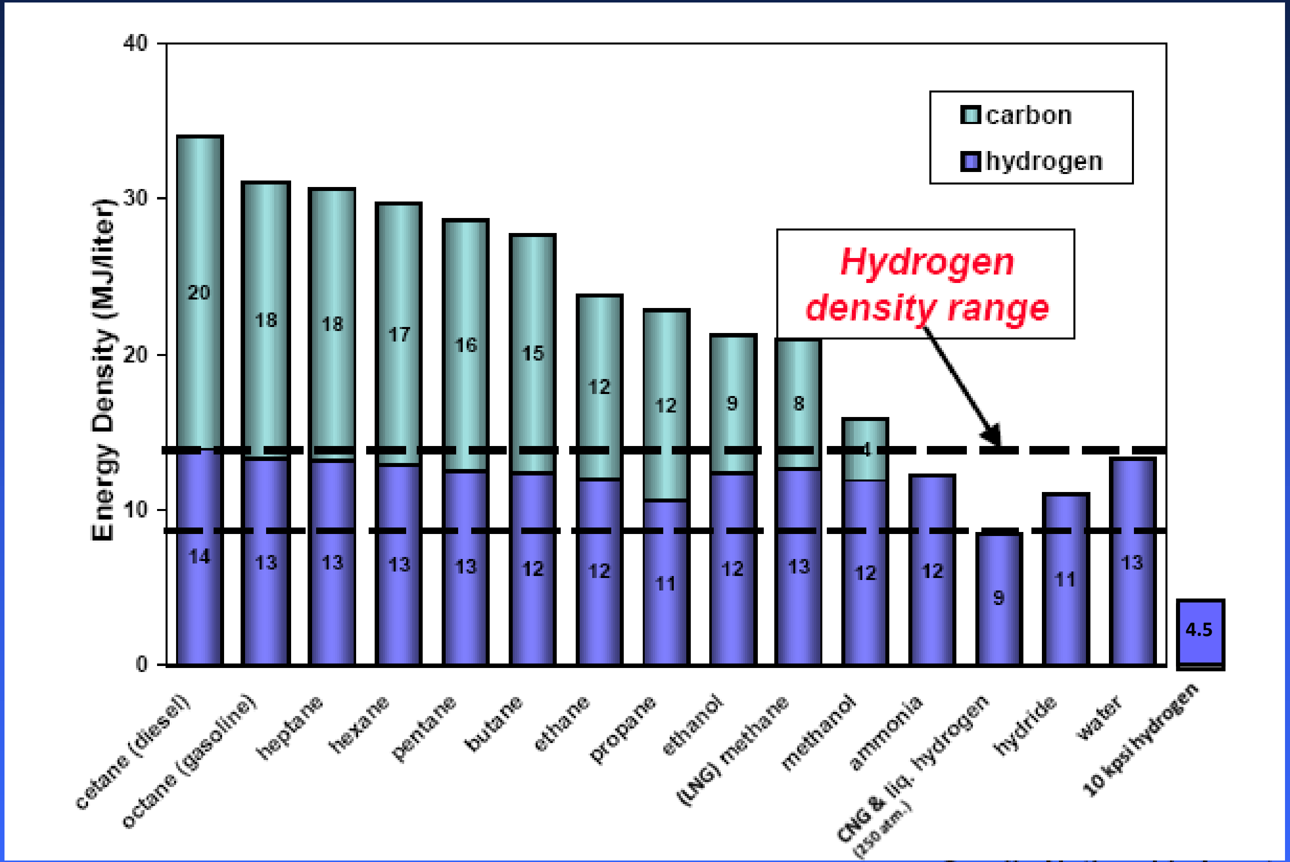
Cost Competitive

Environmentally Optimal – Zero Measurable Criteria Pollutant Emissions

End Use Flexibility – IC and CI Engines, Fuel Cells, Gas Turbines, etc.

Proven, Acceptable Safety Record

Energy densities (LHV) for fuels in liquid state



From George Thomas, BES workshop 5/13/03
Sandia National Laboratories

International Energy Agency 2012

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What causes oil supply disruptions?

The three most common reasons for disruption in the supply of oil are unforeseen technical problems, the weather – such as seasonal storms in the Gulf of Mexico - and civil unrest - such as the civil war in Libya in 2011. Military or terrorist attacks which target energy infrastructure for political motives, or disputes between governments, while rare, are other significant concerns for world oil markets.

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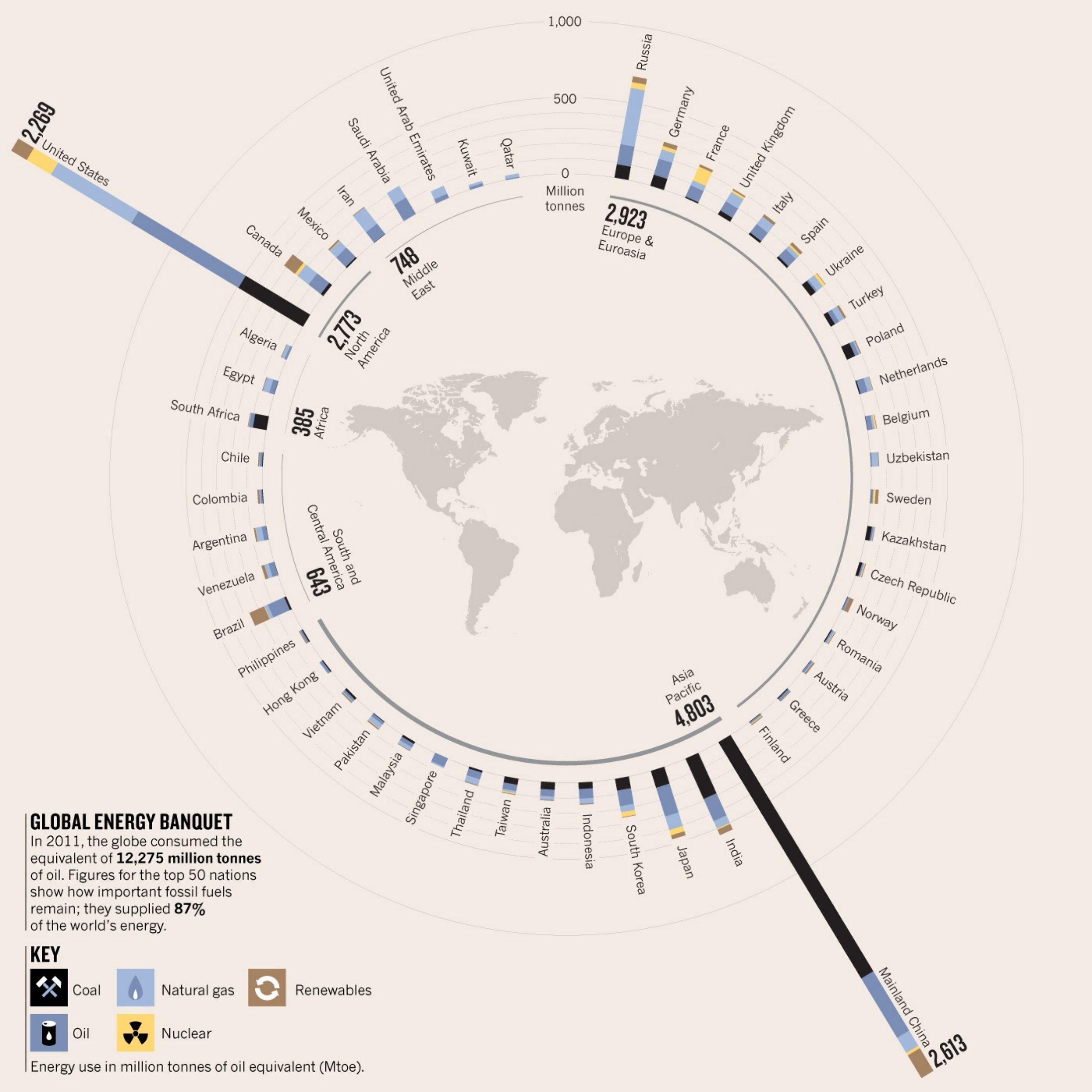
2011 Global Energy Consumption



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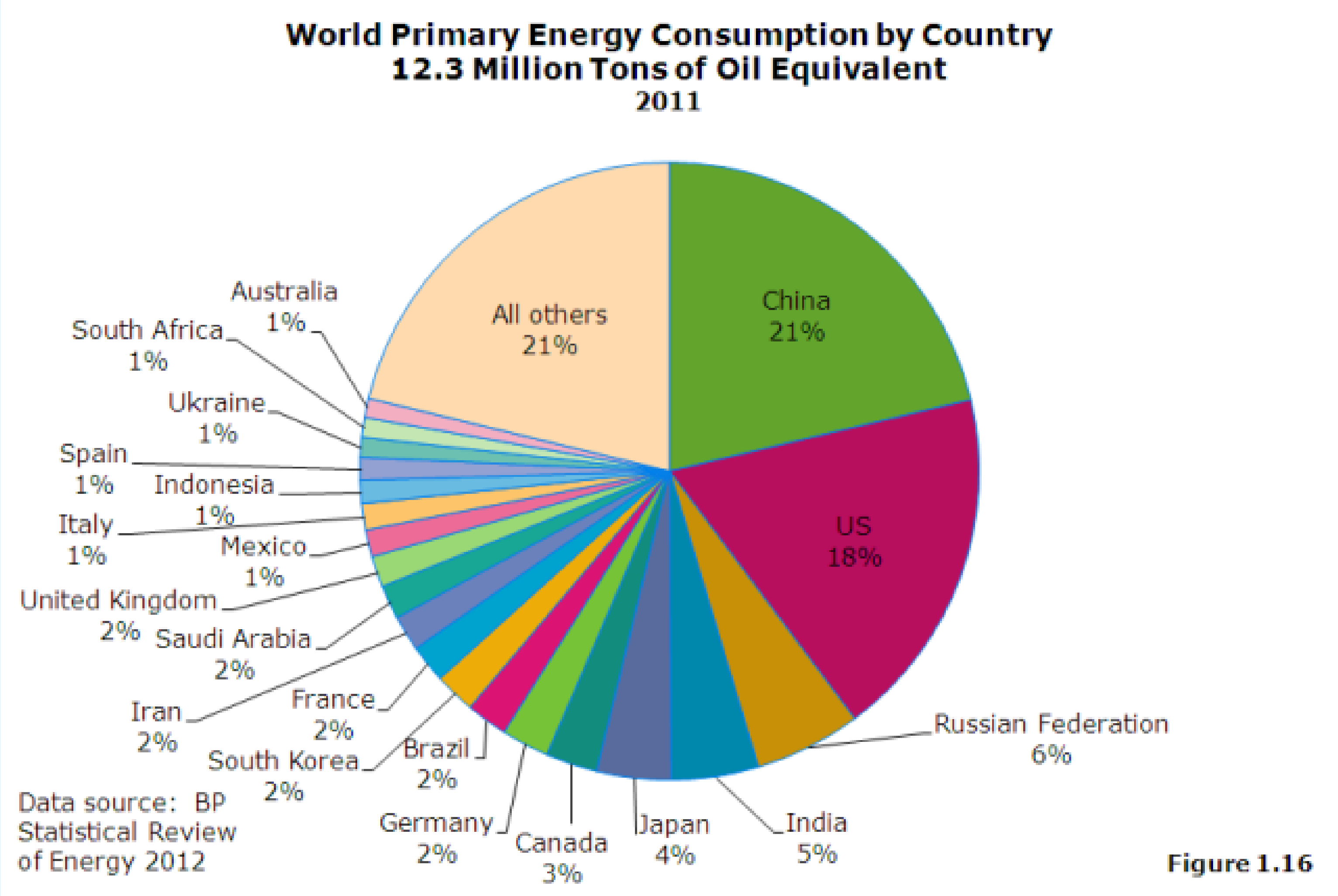
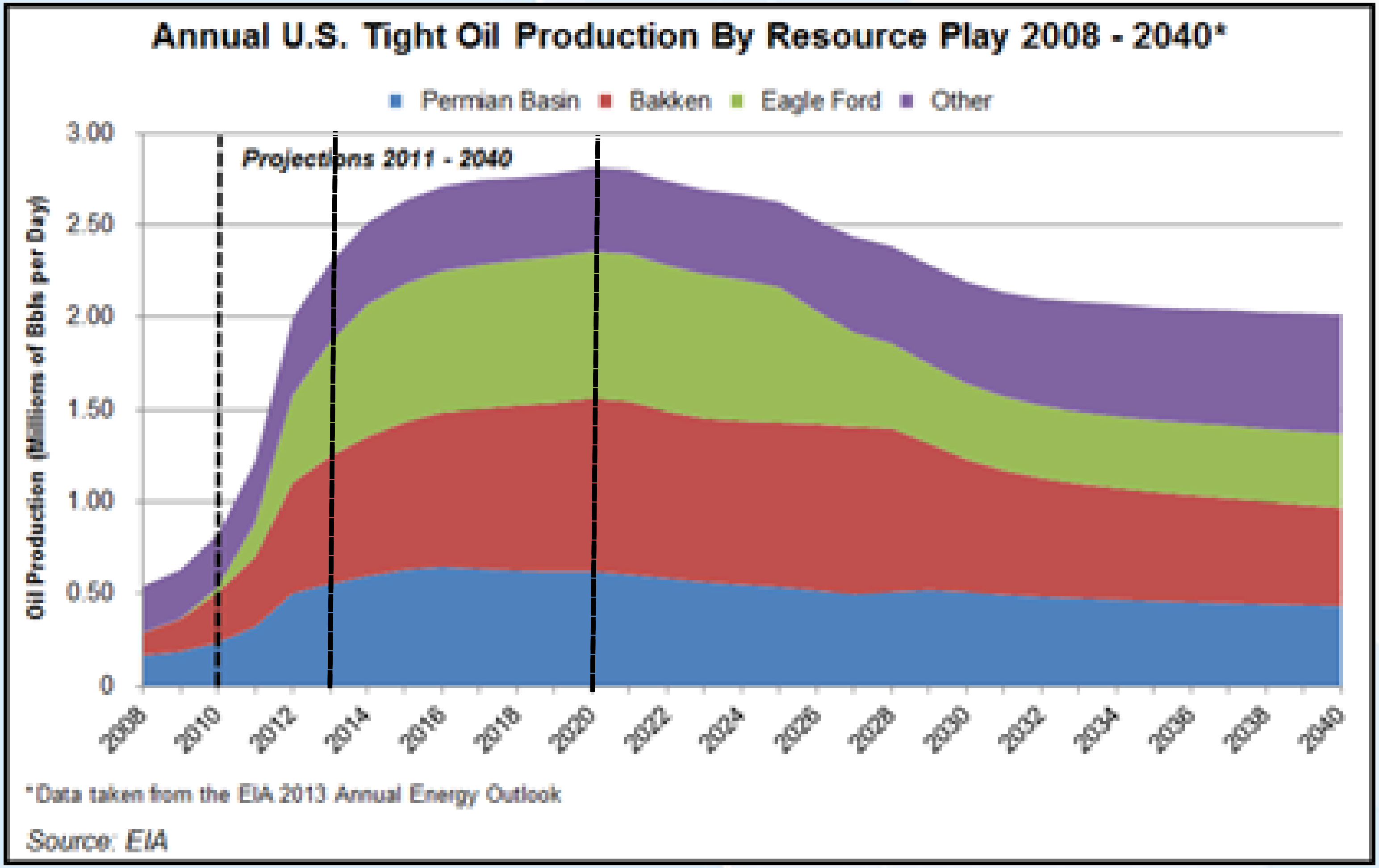
World Primary Energy Consumption 2011



EIA 2013 Outlook



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U.S. 2012 Production – 8.9 million barrels per day. Source: BP SR

British Petroleum R/P Ratio

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	U.S. R/P Ratio		China R/P Ratio	
	2012	2013	2012	2013
Oil	10.8	10.7	9.9	11.4
Natural Gas	13.0	12.5	29.8	28.9
Coal	239	257	33.0	31.0

Reserves-to-production (R/P) ratio – If the reserves remaining at the end of any year are divided by the production in that year, the result is the length of time that those remaining reserves would last if production were to continue at that rate.

Proved reserves of oil – Generally taken to be those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known reservoirs under existing economic and operating conditions.

Source: BP statistical Review of World Energy, June 2012, 2013

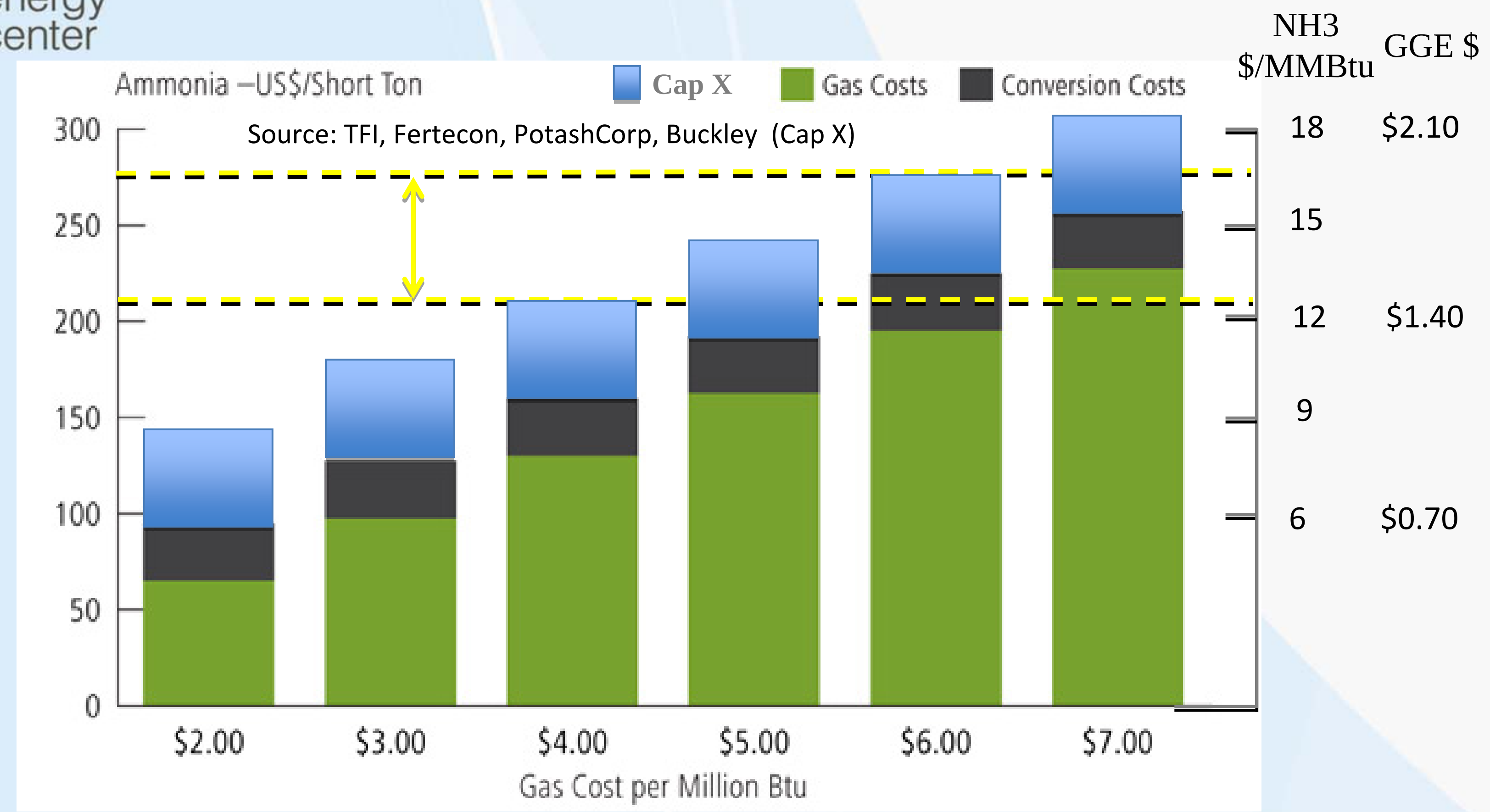
Natural Gas ?

U.S. Gas Volatility, Higher Prices Coming Despite Shales, JP Morgan Exec Says

As part of a "U.S. Century" fueled by global shale gas dominance, domestic natural gas prices will rise and volatility will return in the next three to five years, a JP Morgan executive told participants at the LDC Gas Forum Mid-Continent in Chicago Tuesday.

Source: NGI's Shale Daily, September 16, 2013

NH3 Production Costs w/ Cap X



Gasoline @ $3.50/gallon = $30/MMBtu

Natural Gas Represents More Than 75 Percent of US Producers' Costs
Natural gas is the most important feedstock in ammonia production and, depending on price, makes up 70-85 percent of the US cash cost of producing ammonia. Cap X: $1500/ton, 30 year amortization, ~$50/ton

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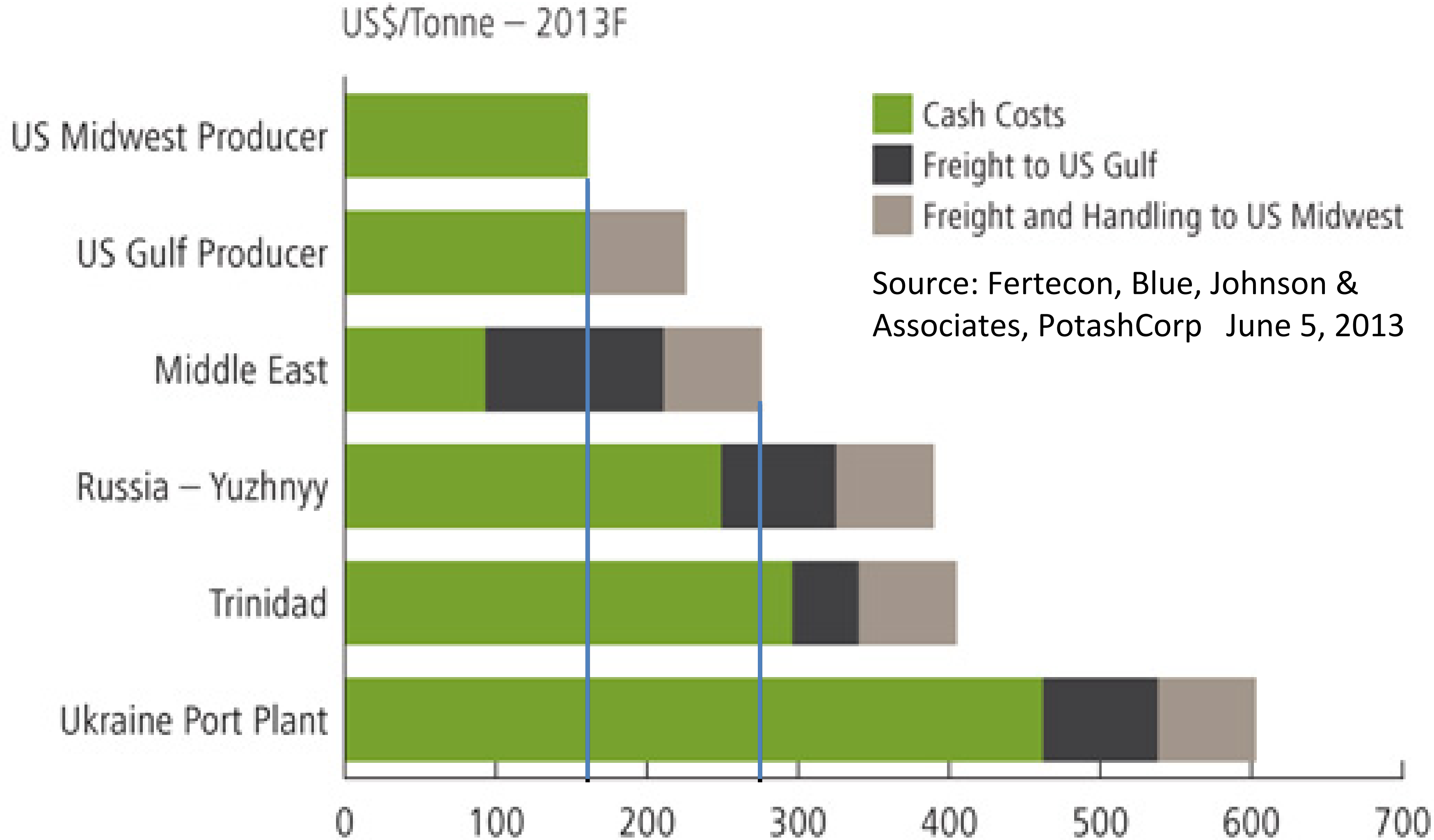
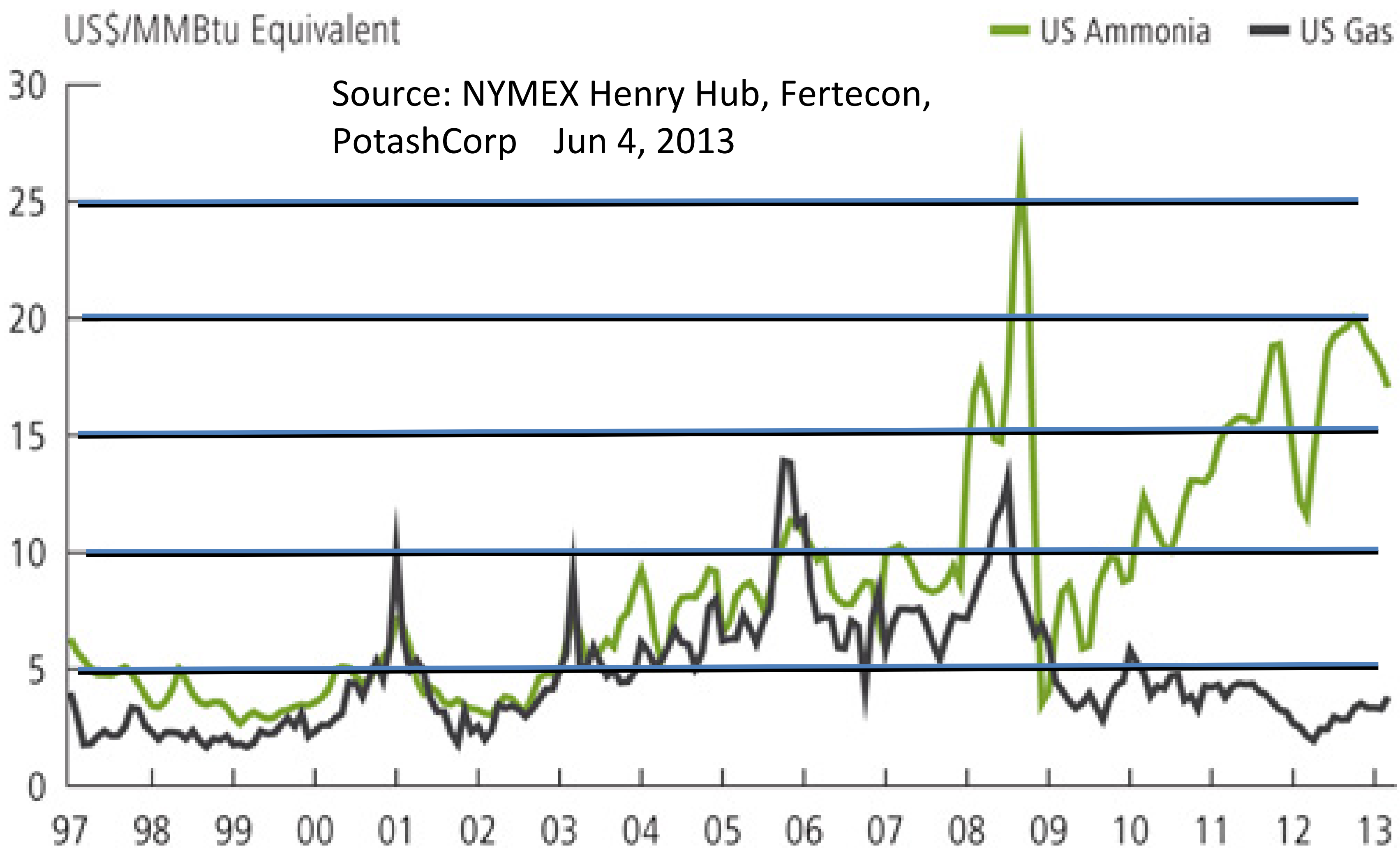
US Midwest Delivered Ammonia Cost

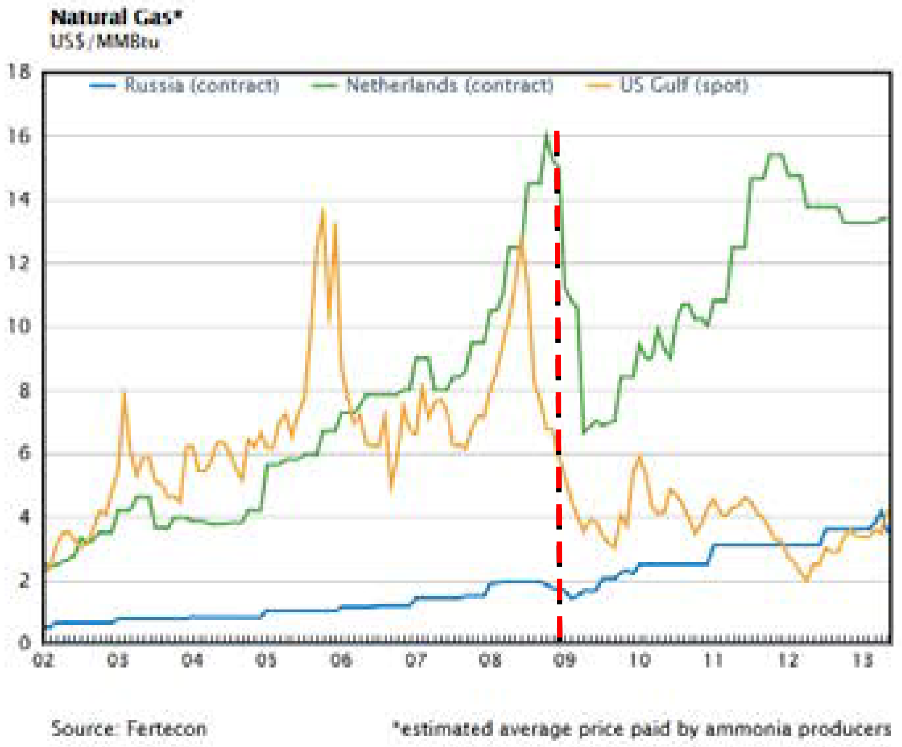


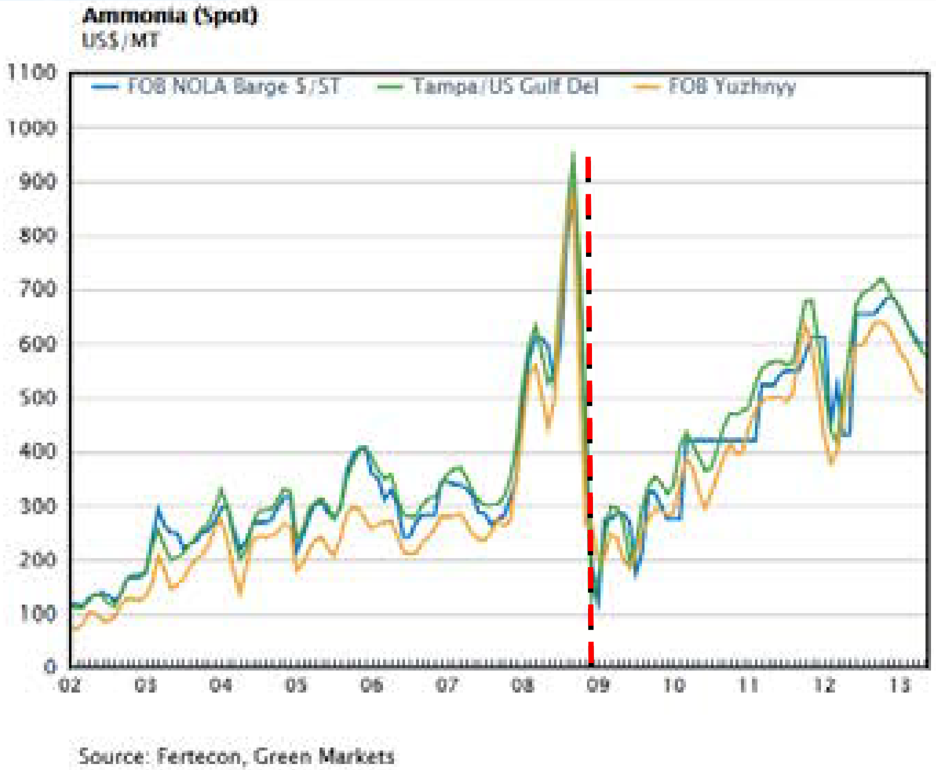
Source: Fertecon, Blue, Johnson & Associates, PotashCorp June 5, 2013

Historical NH3 vs NG Costs



Natural Gas and NH3 $





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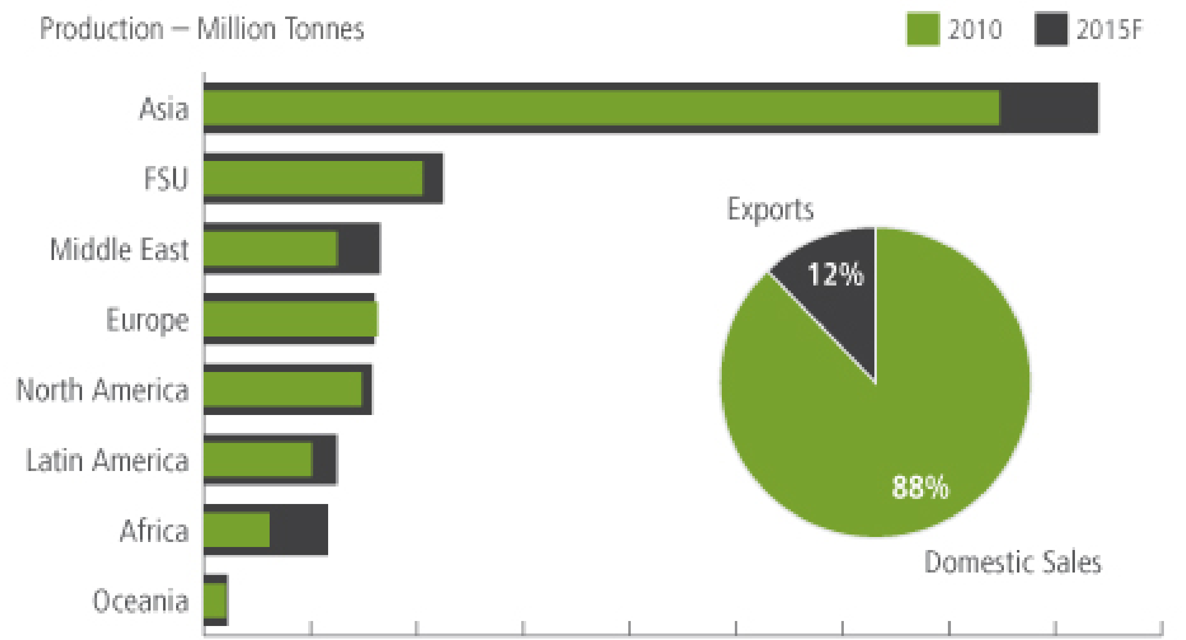
NH3 Production



Source: Fertecon

Delivery Infrastructure

NH_3 is in the top three chemicals shipped worldwide.

Ammonia Storage & Transport

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U.S. Ammonia Pipeline

Nearly 3000
Miles Total

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Iowa NH3 Outlets

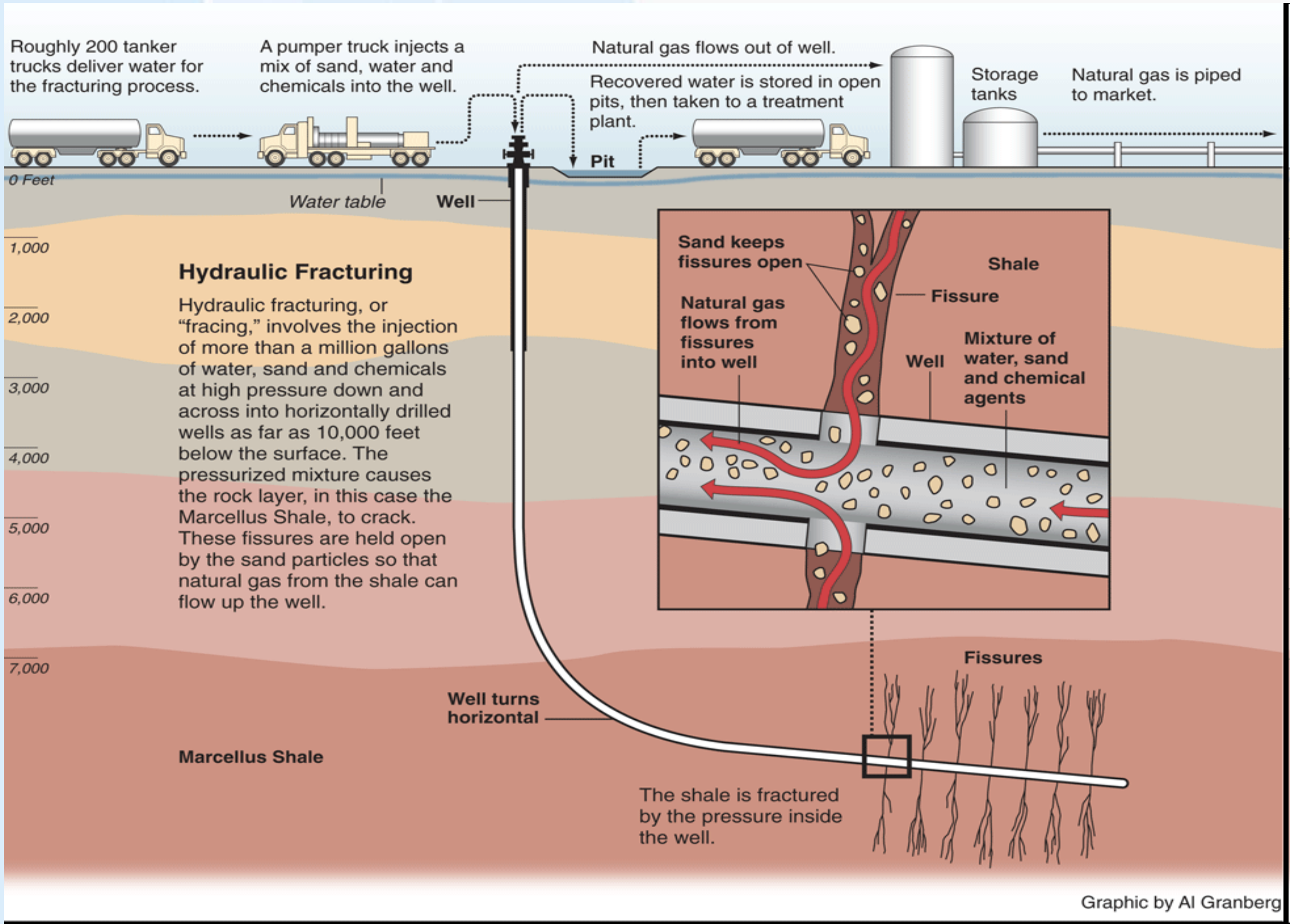
Over 800 retail ammonia (the "Other Hydrogen") outlets currently exist in Iowa.

NH_3 and Natural Gas

Convert CH4 to NH3 at well head, sequester CO2 in enhanced oil recovery (EOR) and natural gas wells to extend well production. Use natural gas pipeline (with modifications) to ship NH3.

1.5 times more energy capacity when transporting NH3 than CH4 for a given pipeline size

More efficient energy transport



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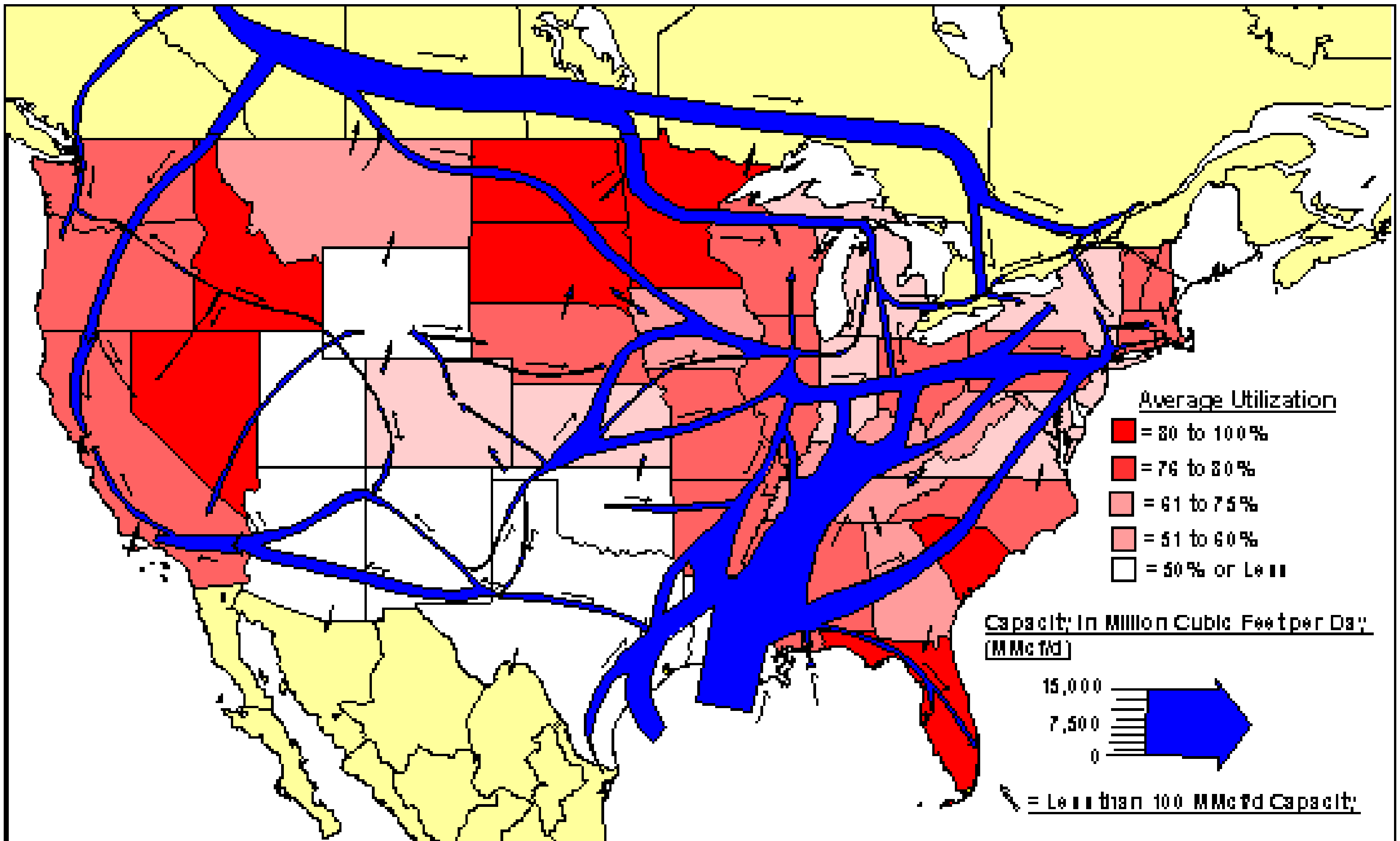
Natural Gas Pipelines



EIA

Fueling Station – Refrigerated NH3

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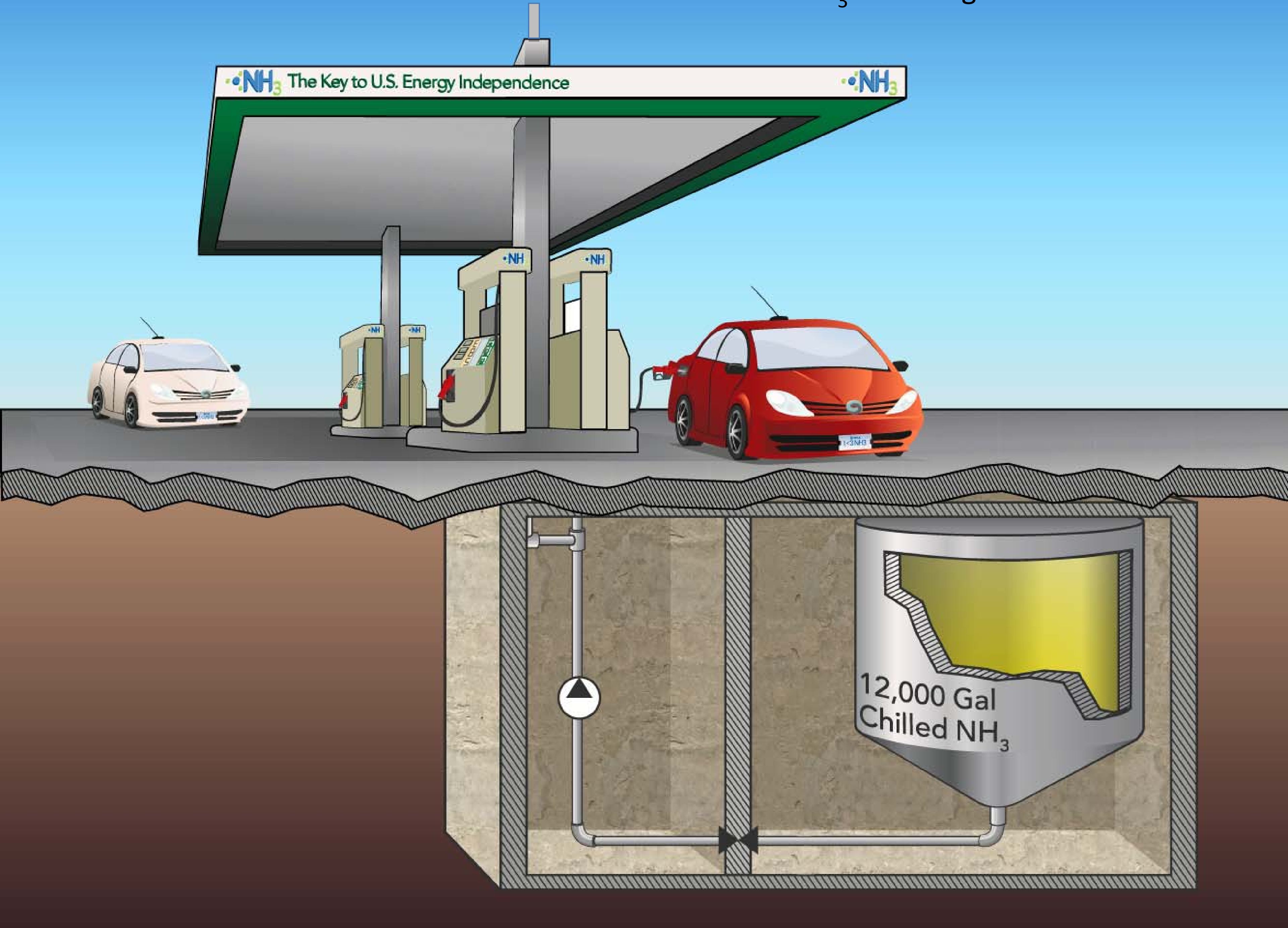
The refrigerated ammonia storage system is designed such that if a small or significant release of ammonia were to occur in the storage, heating, or pumping systems, the released ammonia liquid and vapor would be contained in a vault and vented through a vertical stack extending upward. As the ammonia vapors warm and disperse from the elevated stack, the ammonia/air plume will be positively buoyant and will have no ability to slump back to grade. This storage method essentially eliminates the grade-level risk associated with the storage of refrigerated ammonia.

In summary, the hazards and risks associated with the truck transport, storage, and dispensing of refrigerated anhydrous ammonia are similar to those of gasoline and LPG. The design and siting of the automotive fueling stations should result in public risk levels that are acceptable by international risk standards. Previous experience with hazardous material transportation systems of this nature and projects of this scale would indicate that the public risk levels associated with the use of gasoline, anhydrous ammonia, and LPG as an automotive fuel will be acceptable.

Source: CQRA 09-06-6708, Quest Consultants Inc., 2009

NH_3 Refueling Station



Safety I

- **NH_3 is a common, naturally occurring chemical found in or used by nearly all animal life forms. It is not a carcinogen and is not a greenhouse gas. Its ozone depletion number is zero.**
- **NH_3 is safer than propane and as safe as gasoline when used as a transportation fuel.**
- **The Iowa Energy Center funded a comparative quantitative risk assessment (CQRA) study completed March 2009, by Quest Consultants Inc., Norman, Oklahoma. "Comparative Quantitative Risk Analysis of Motor Gasoline, LPG, and Anhydrous Ammonia as an Automotive Fuel", June, 2009.**
- **"Safety assessment of NH_3 as a transportation fuel", Nijs Jan Duijm, Frank Markert, Jette Lundtang Paulsen, Riso National Laboratory, Denmark, February, 2005**

Safety II

- **NH3 plant operators – hydrogen vs NH3**
- **NH3 safety is an engineering issue. It can be made to be as safe as is necessary.**
- **NH3 is classified by DOT as a non-flammable liquid and an inhalation hazard (not a poison)**
- **The degree of safety for NH3 Fuel is an *engineering decision* and does not require any technology miracles/breakthroughs (unlike hydrogen and electric vehicles).**

Delivery Truck Risk Transects

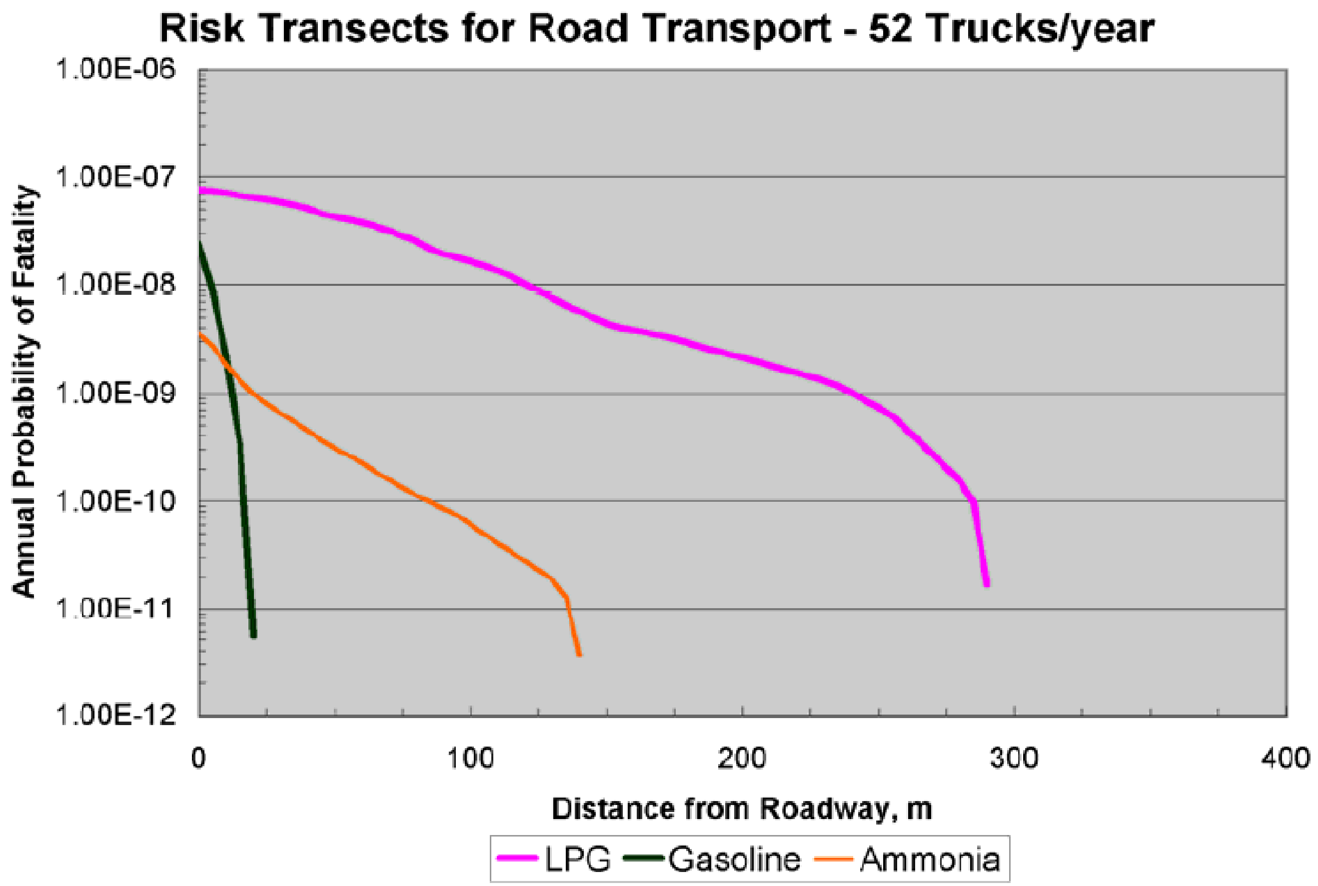


Figure 6-3
Risk Transects for the Truck Transport of Gasoline, LPG, and Refrigerated Ammonia

Fueling Station Risk Contours

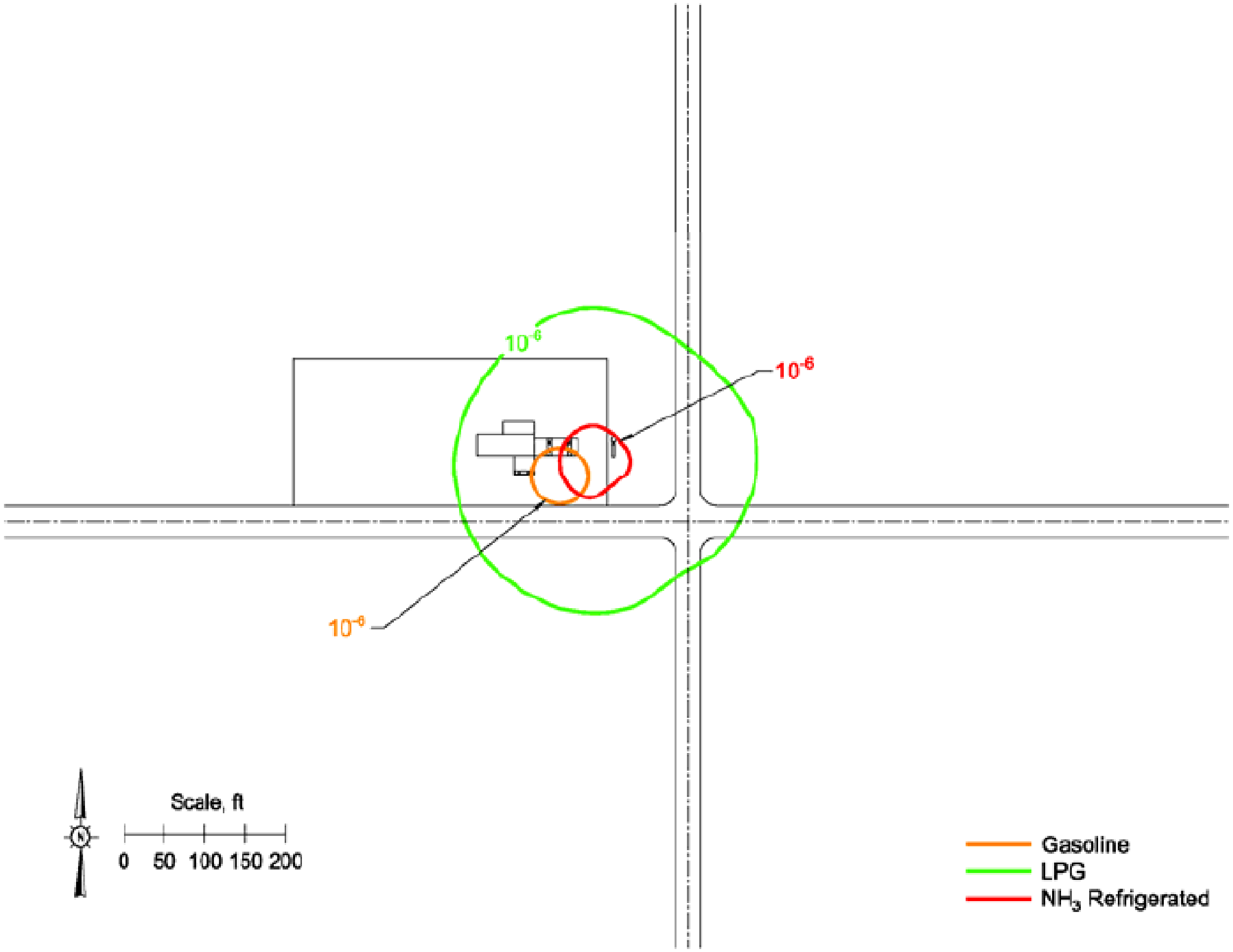


Figure 6-8
1.0 x $(10)^{-6}$ Risk Contours for Three Automotive Fuels

Vehicle Fuel Tank Risks

It is also important to note that the risk associated with traveling in a vehicle powered by any one of these fuels is dominated by accidents that do not result in a release of the fuel. As described in the National Safety Council database referenced in Section 1, very few traffic accidents result in a release of the fuel powering the automobile. Since anhydrous ammonia and LPG are stored in similar pressurized tanks, there is no reason to believe that the risks associated with the passengers in an automobile would go up or down due the use of anhydrous ammonia as the fuel.

Source: CQRA 09-06-6708, Quest Consultants Inc., 2009

Vehicles: On-Board Storage Fuel Tanks

Atmospheric (Non-pressurized) cryogenic tanks provide higher energy density and safer operating conditions than pressurized tanks

NH_3: -28F BP

NH_3: -108 MP (transparent solid)

LNG: -265F BP

LH_2: -420F BP

Cryo NH_3 can be contained in 250psi rated tanks if stored beyond atmospheric pressure stage. LNG and LH_2 must be vented if stored beyond "hold " time.

Properly designed, pressurized (250 psi rated) NH_3 vehicle fuel tanks meet international requirements for acceptable safety.

Comparison of Minot with Lac-Mégantic Derailments

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Comparison of Minot with Lac-Mégantic Derailments

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Minot ND Spill

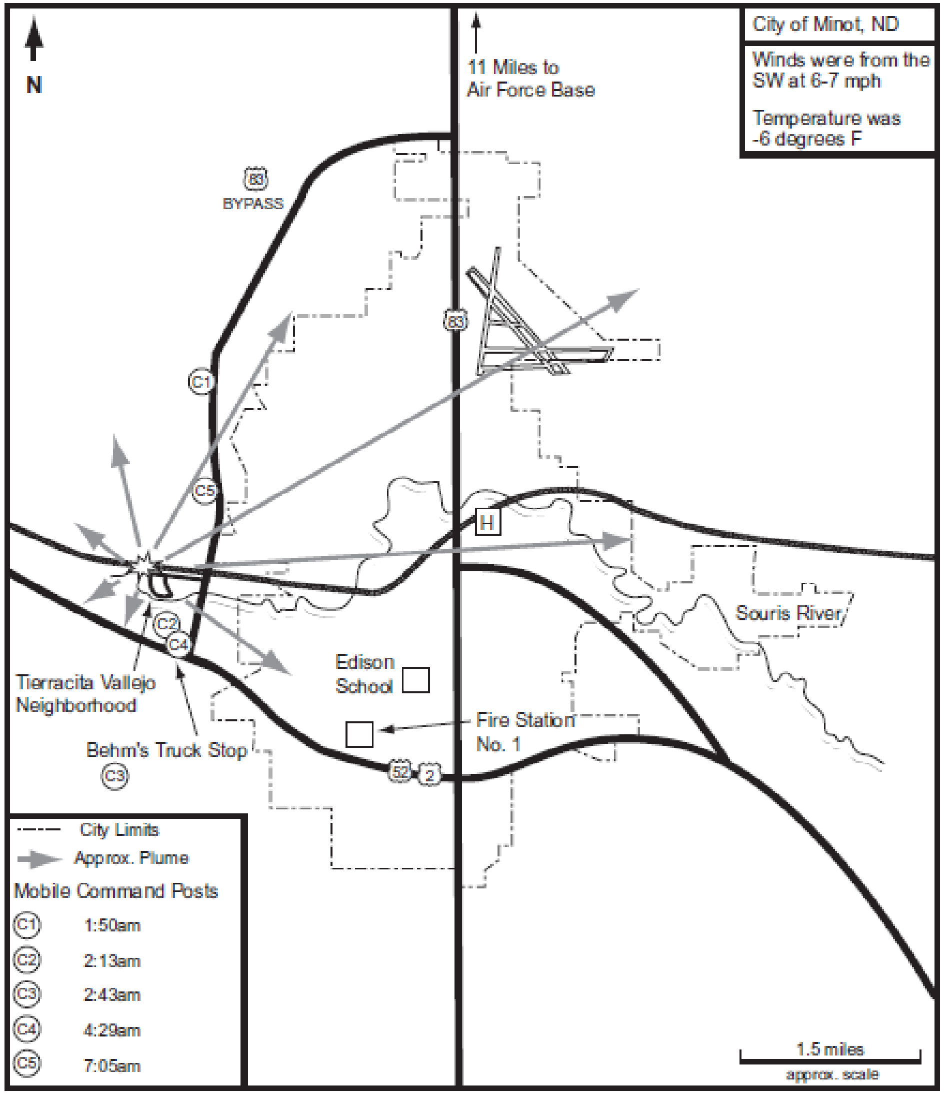

Figure 5. Map of derailment area.

Crude Oil vs NH3 Train Derailment Consequences

	Lac-Mégantic	Minot
Cargo	Crude oil	Anhydrous ammonia
Date	06-Jul-13	18-Jan-02
Time	01:15	01:37
Train speed	56 mph	41 mph
Cars in train	72	112
Ruptured cars	4	5
Gallons released	1,500,000	240,000
People living within affected area	2,000	11,600
Fatalities	47	1
Sustained serious injuries	?	11
Minor injuries	?	322
Damages/Clean-up Costs	$50million/$200 million	$2 million/$8million

Sources: David Nugent, 9/19/2013 correspondence. Wikipedia. NTSB/RAR-04/01.

West Texas Explosion – Not NH3 Related

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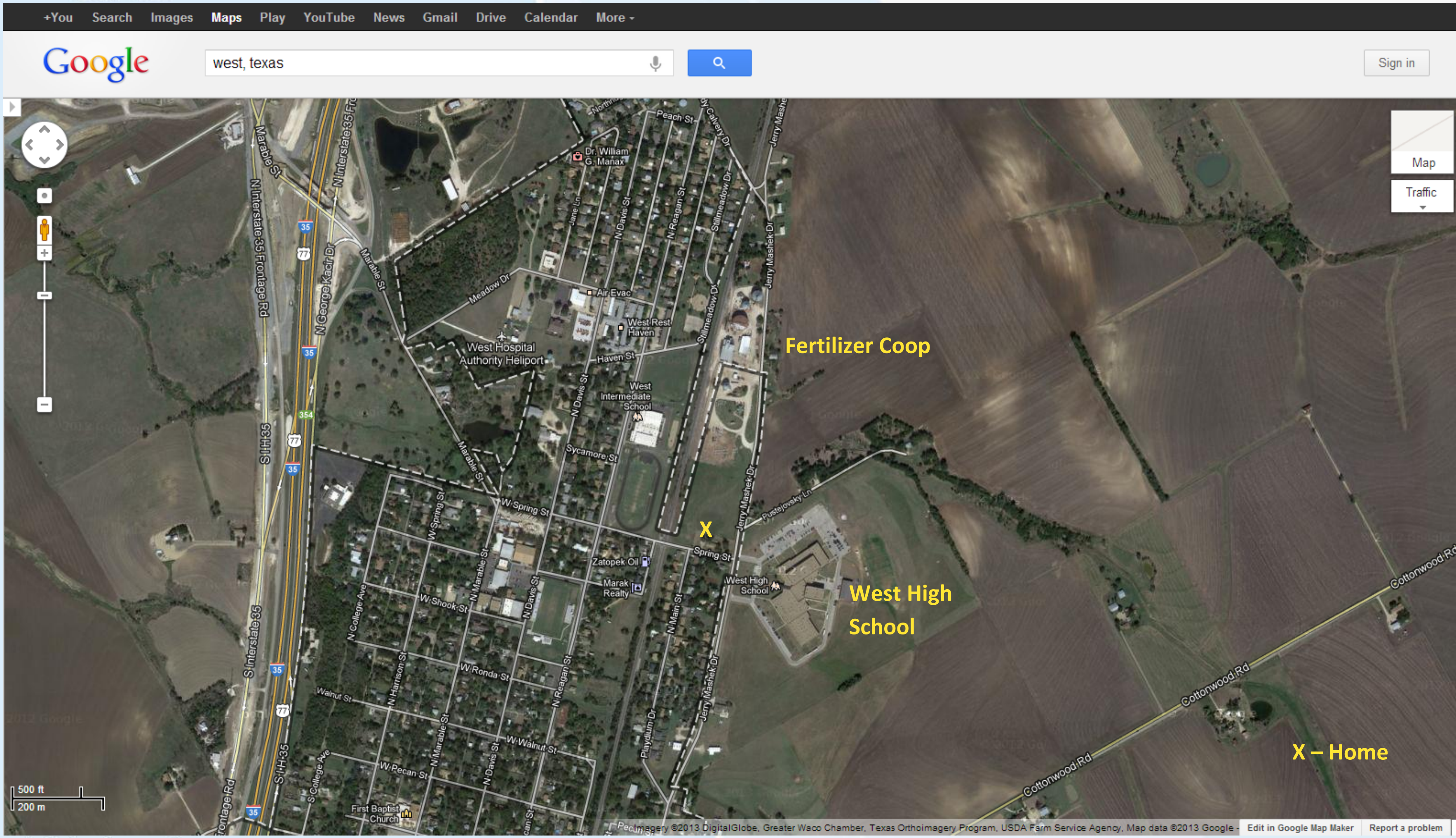

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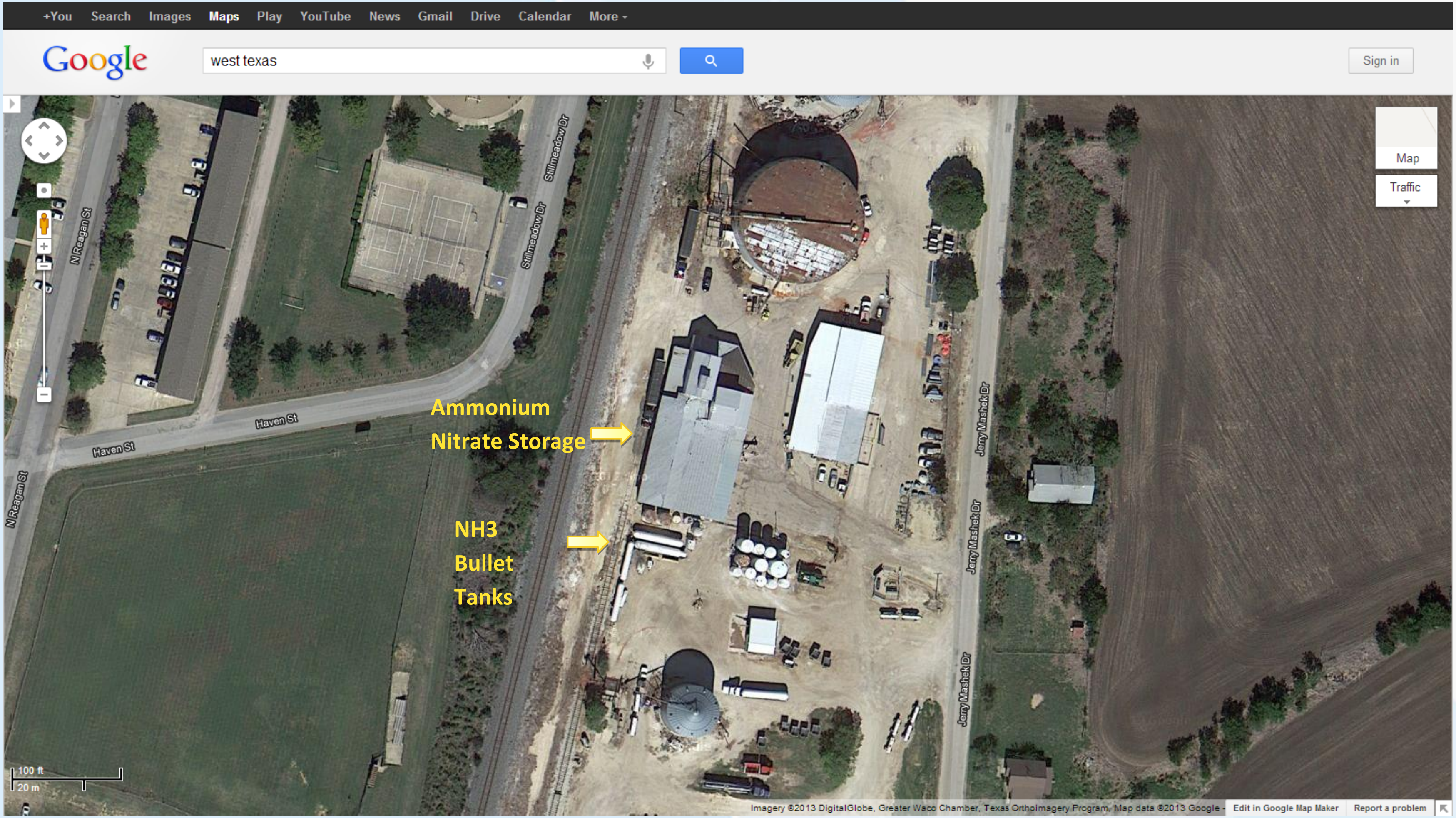
West Texas Explosion – Not NH3 Related



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West Texas Explosion – Not NH3 Related

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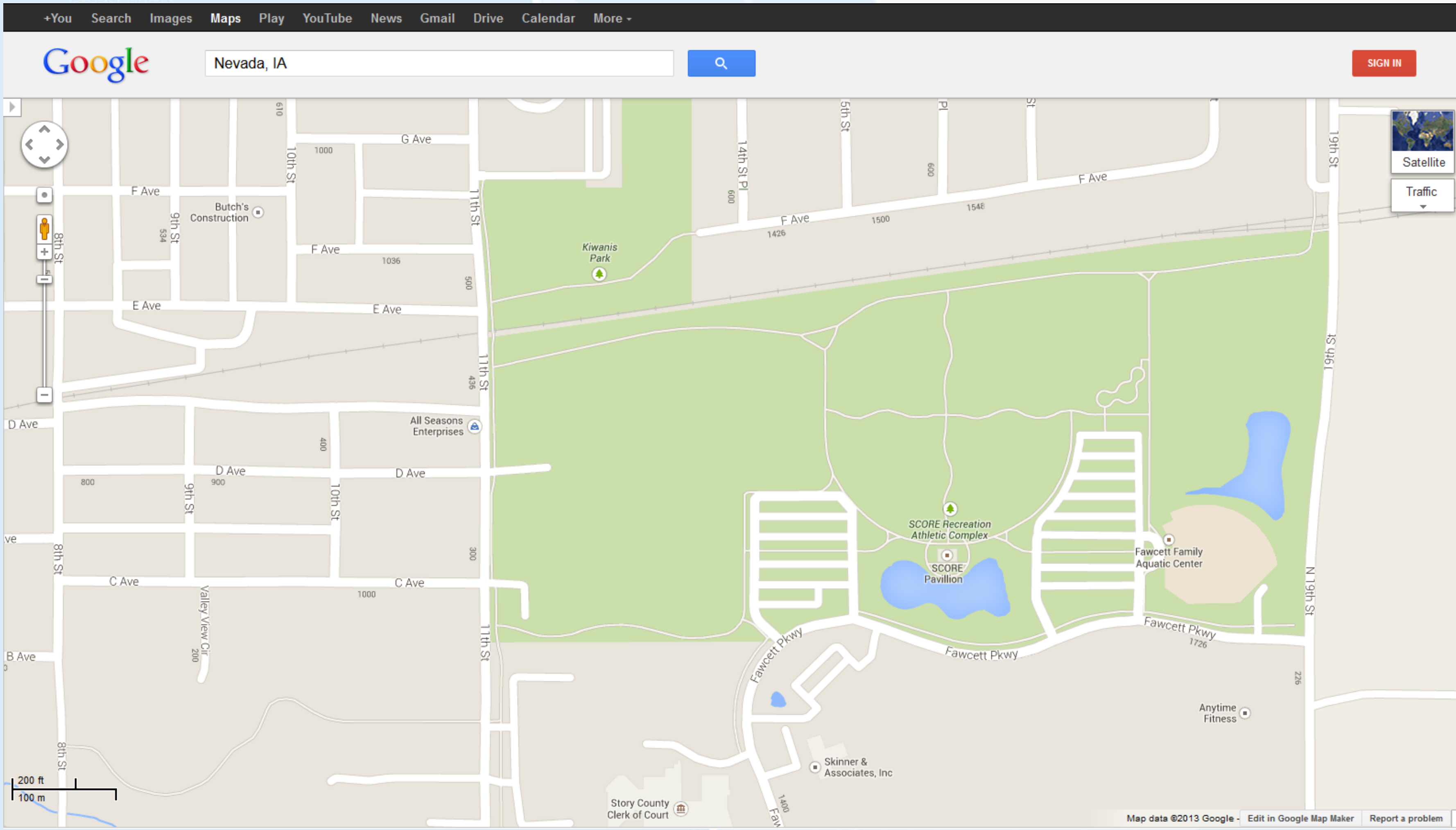
Nevada, Iowa



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Nevada, Iowa

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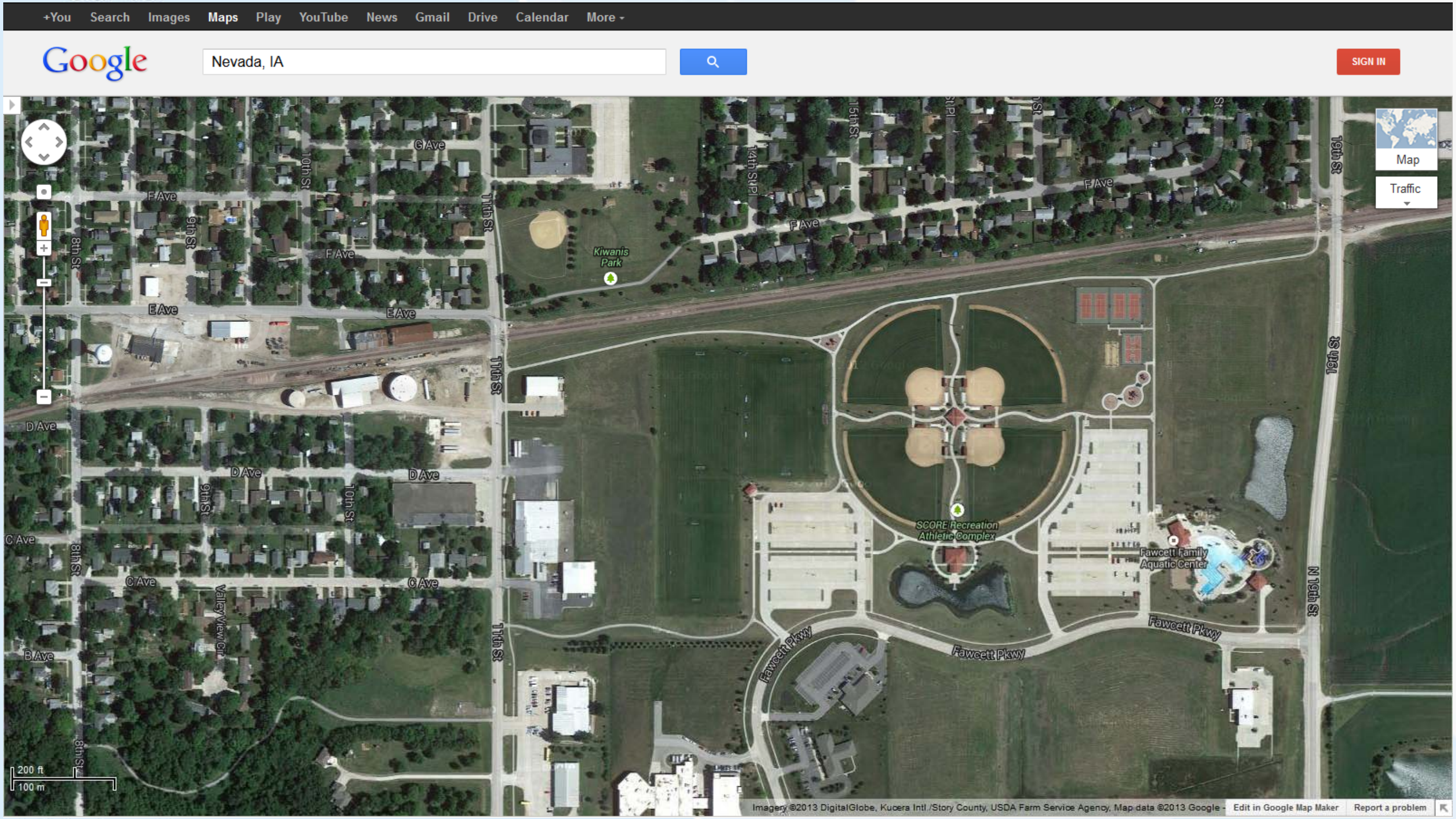
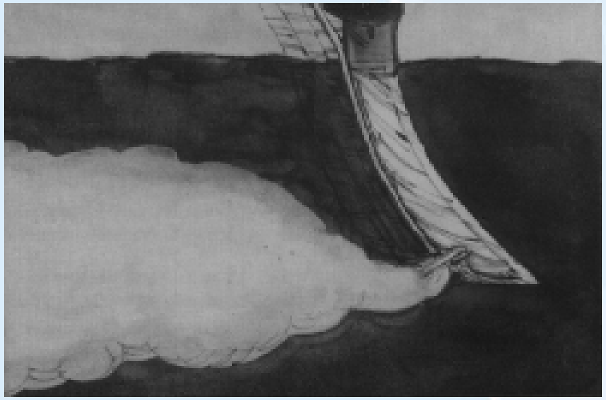


NH3 Fertilizer Application



Anhydrous ammonia expands into a gas as it is injected into the soil where it rapidly combines with soil moisture.

Potential End Use Applications

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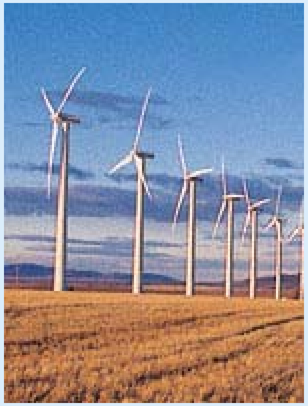
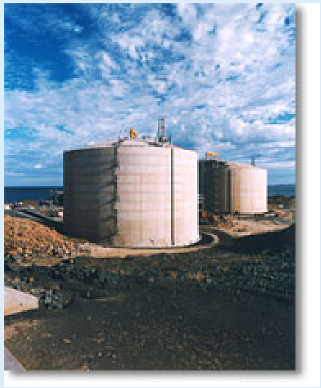
- Spark-Ignition Internal-Combustion Engines
- Diesel Engines
- Direct Ammonia Fuel Cells
- Gas Turbines
- Gas Burners (including residential furnaces)

Future Compatibility



Hydrogen + Nitrogen

Ammonia

Storage & Delivery – Pipeline, Barge, Truck, Rail

Stationary Power

Fertilizer

Transportation

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More Work To Do

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Additional Research Areas?
Demonstrations - vehicles/engines/gas burners/others?
Marketing?
Auto Manufacturers Participation?
Collaborations?
International Support
Federal/DOE Support?
State Support?
?

Summary 1

- NH_3 meets critical 2015 Freedom Car targets today
- NH_3 has a very extensive, worldwide transportation and storage infrastructure already in place.
- H_2 and NH_3 can have very low tailpipe greenhouse gas emissions (with controls)
- H_2 and NH_3 can be made from electricity and water (+air for NH_3)
- NH_3 can replace diesel fuel, gasoline, natural gas and propane in many fuel-related applications
- NH_3 is a hydrogen dense chemical, ~50% greater (volume basis) than 10k psi hydrogen.

Summary 2

- **Most NH3 is currently produced from coal and natural gas**
- **NH3 can be produced using renewable energy (Including wind, solar, OTE, hydro, etc.)**
- **NH3 diesel (CI) and spark-ignition (SI) engines have been demonstrated**
- **Direct NH3 fuel cells are being developed**
- **NH3 is not a greenhouse gas. It is an very prevalent, naturally occurring chemical**
- **Any transportation fuel has associated safety risks but NH3 is as safe as gasoline and safer than propane according to two, highly-credible studies.**
- **Hydrogen stored, delivered and utilized in the form of NH3 has numerous significant benefits.**